NEURAL BOTTOM-UP AND TOP-DOWN PROCESSES IN LEARNING AND TEACHING

Theresa Schilhab*

Contemporary neuroscience perspectives on cognition allow for detailed understanding of the co-activity of unconscious, automatic 'bottom-up' processes and conscious 'topdown' processes. In this theoretical article I argue that by using direct experiences or metaphors, teachers can manipulate the neural foundation bottom-up or topdown so as to influence learning, giving teachers the conceptual tools they need to understand how specific measures - instructional and experiential teaching, as well as linguistic explanations - may work. The article thus describes how embodied cognitive approaches may be effective for teaching and learning and thus contribute to a new exchange between theoreticians and educational practitioners.

Keywords: Neural correlate, concept, metaphor, direct experience, attention, top-down, bottom-up, executive function, derived embodiment

> Every moment of waking life, the human brain realizes mental states and actions by combining three sources of stimulation: sensory stimulation made available by and captured from the world outside the skin (the exteroceptive sensory array of light, vibrations, chemicals, etc.), sensory signals captured from within the body that holds the brain (somatovisceral stimulation, also called the interoceptive sensory array or the internal milieu), and prior experience that the brain makes available by the reactivation and reinhibition of sensory and motor neurons (i.e., memory). These three sources – sensations from the world, sensations from the body, and prior experience – are continually available, and they form three of the fundamental aspects of all mental life. Barrett (2009: 330).

Background

Neuroscience has increasing influence on how society views learning and knowledge. Neuroscience is used in explanations of consumer mentality (Lindstrom, 2010), religious needs (Connor, 2009) and coaching (Ghadiri et al., 2012). Indeed, neuroscience *is* relevant for pedagogic theories. For example, neuroscientific studies of how language is embodied – 'grounded cognition' (e.g. Barsalou, 2008) – are pivotal for the relation between non-explicated knowledge and knowledge, in which we are being taught and tested. These studies should contribute to research in the relation between embodied and conceptual knowledge in general and also to research on the value of particular pedagogical initiatives such as outdoor school (Corazon et al., 2012; Schilhab, 2011); as well as elucidate how the shift from print books to tablets influences reading comprehension (Mangen & Schilhab, 2012).

But scientific knowledge uniting neuroscience with pedagogy (educational neuroscience) is still sometimes conceived as illicitly crossing scientific boundaries. The challenge meeting educational neuroscience is how to meaningfully combine the quantitative, nomothetic third person approach with the qualitative, idiographic first person approach (e.g. Bruer, 1997; Fischer, 2009).

How may knowledge of for example grounded cognition and neurally informed conceptualisations of learning as exemplified by Barrett's quotation at the beginning of this paper contribute to pedagogic research and practice? How may the nervous system's sophisticated, placid receptivity (e.g. Deacon, 2012) that seems to leave out first person experiences become a useful tool in the field of education? And more specifically how may knowledge of the neural level improve insight at the pedagogical level?

In this paper, I argue that neural complexity may lend itself to operationalisations that can be useful to educators especially within areas that rely heavily upon abstract concepts. I argue that by using direct experiences or metaphors resulting in 'derived embodiment' (to be discussed more fully below), teachers can manipulate the activity of the so-called neural correlates in such a way as to improve learning. I conjecture that conceptualisation of knowledge at the neural level may introduce new levels of description that are relevant to pedagogy.

In what follows, I discuss the implications of Barrett's three components in an attempt to operationalise descriptions at the neural level in a way that makes sense in terms of educational practice. I begin by briefly expanding on the notion of neural correlates, conscious and unconscious processes and aspects of attention.

The neural corroboration of learning

In the passage quoted above, Barrett describes how at each instant our mental life is drawing on multiple sources. At any given moment, cognitive occurrences – be they ideas, desires, the needs for actions – are composed of many different processes (e.g. Deacon, 2012). The mental ‘melting pot’ implied by Barrett is sustained by a many-faceted ‘product’ – a so-called neural correlate, which, in a very loose sense, corresponds in part to the ‘disturbances’ (external and internal stimulations) from the present and the past and in part to the experiences of these disturbances. Thus, these three components; stimulations from the external and internal milieu and memory, comprise both conscious and unconscious processes, which means that some of the processes are initiated and proceed without the individual recognising and controlling them and thus emerge ‘bottom-up,’ while others may be brought under conscious control (see also Beilock, 2010; Calvo & Gomila, 2008).

For example, when Barsalou (2009) describes a bicycle being perceived (an activity that draws primarily on the first component of Barrett’s tripartite division), several conscious and unconscious processes are at play (2009:1281):

> When an entity or event is experienced, it activates feature detectors in the relevant neural systems. During visual processing of a bicycle, for example, neurons fire for edges and surfaces, whereas others fire for colour, configural properties and motion. The overall pattern of activation across this hierarchically organized distributed system represents the entity in vision. Analogous patterns of activation in other sensory modalities represent how the bicycle might sound and feel. Activations in the motor system represent actions on the bicycle. Activations in the amygdale and orbitofrontal areas represent affective reactions.

Moreover, simultaneous activations across modalities triggered by, for example, the sight of the bicycle allow for neural connections to be increasingly available. As a result of this co-activation, neurons that were not previously active together are recruited to form a novel ensemble of neurons (Pulvermüller, 2011; 2013) responsible for sustaining the experience of the bicycle after the stimulation itself (i.e. the sight of the bicycle) has ceased.

The complexity of the neural correlate that sustains conscious and unconscious processes across modalities is also at play in more advanced cognitive functions, such as conceptual knowledge, which we usually perceive as more consciously controlled. Studies in cognitive neuroscience suggest that language learning draws on perceptual, experiential, sensory–motor and consciously controlled components (e.g. Schilhab, 2015b).

The coupling of these components occurs when, early in life, we learn language as a result of two classes of phenomena occurring simultaneously: our perceptual access to the phenomena and events referred to in language accompanying the linguistic learning event (Pulvermüller, 2005).

For instance, when pre-linguistic children are introduced to the concept 'dog,' they typically experience an actual dog. The neural correlate that emerges when acquiring the linguistic understanding of 'dog' therefore couples the sensory experience of the language processing, the sounds, the articulation and the sensory–motor experience of a real dog (Pulvermüller, 2005; Schilhab, 2011a; 2015a). The neural correlate of 'dog' thus comprises several processes of which we are not normally aware, since they are not at the centre of our conscious focus: e.g. the dog breathing, its having four legs, the feel of its coat. These experiences may still contribute to the activity of the ensemble as a result of our unconscious susceptibility, however, as this is a susceptibility that occurs bottom-up (e.g. Barsalou et al., 2003; Hesslow, 2002).

An important aspect to bear in mind is that pervasive sensitivity persists throughout life and is not confined to the acquisition of language. According to Sheckley and Bell (2006), most connections between neurons form in response to experiences of objects, events or situations that stimulate changes in the state of the body. This could be the eating of an ice-cream or the handling of keys while locking the door. They name this a 'change-of-a-body-state' (COBS) experience.

> The more repetitions we have of a change-of-a-body-state (COBS) experience and the more intense the COBS experience, the more likely the brain is to form a durable, fired-together-wired-together (FTWT) circuit to "remember" the experience.

Here, Sheckley and Bell (2006) seem to suggest that the awareness of COBS is criterial to the strength of the FTWT assembly, which, on the other hand, may be criterial to the ability to grasp a concept. The experience of actual phenomena results in COBS experiences which 'suffuse' the understanding of the concept. The extent of neural activity triggered by stimuli from internal and external sources as well as memory potentially eliciting a COBS is overwhelming, even during a banal coffee experience (Sheckley & Bell, 2006: 47):

> When durable FTWT circuits of an event such as drinking coffee are formed, whether by constant repetition or by an intense event, the brain includes with that circuit not only explicit associations (the restaurant in Belize, where you had the best coffee, ever) but also a variety of nuances in smell, variations in colour of the foam on top of the cup, or even the

subtleties associated with the brown eyed person who waited on you. These implicit associations are stored as tacit knowledge.

Attention makes the difference

At first sight, it seems as though we are largely merely sounding boards for influences in the world over which we have no control, triggered as they are more or less automatically. Although this might to some extent be true, in we have reason to believe that we have at least partial control over our thoughts and can decide what to attend to. This internal 'mind control' has implications both for learning and for how teaching may be meaningfully organised and therefore ultimately for how conceptualisations of knowledge at the neural level may be relevant to pedagogy.

All mammals are born with an attention mechanism that aids in sorting out the overwhelming amount of information (e.g. Kaplan & Berman, 2010)[1]. E*xogenous* attention is responsible for perception and processing of stimuli that are potentially important; for example, the sound of a car horn when you cross the street chatting with a friend. Here, attention is governed by external events bottom-up, because the reaction is prompted automatically (Wetzel et al., 2006). The exogenous attention is closely linked to sensory modalities.[2]

In addition, the *endogenous* attention is under conscious control, and thus acts 'top-down.' Endogenous attention is involved when we imagine historical events or calculate without the use of paper, and is therefore much in use in traditional schooling. This kind of tasks draws on the so-called executive functions involved in, for instance, planning, error-correction, and decision-making (e.g. Diamond, 2013; Bagetta & Alexander, 2016). It is also endogenous attention that allows us to perform 'offline' tasks (Wilson, 2002), i.e. tasks that do not depend on relevant information from the environment (e.g. Schilhab, 2013a), while keeping disturbing stimulations at bay (Vandenhuyse et al., 2010).[3]

According to cognitive studies on the impact of attention on the intensity of neural activity, if one directs attention towards the periphery of conscious processes – for instance, if one thinks about the fox's tail when imagining a fox (Pearson et al., 2013) –, one may apparently increase the neural activity of the corroborating correlate. This increase entails that the perceived experience of the processes is manifest more clearly (e.g. Andersen, 2008; Kam et al., 2011; Kashiwase et al., 2012). Endogenous attention reinforces the activity of specific neural structures, which are then better able to assert themselves in consciousness and may subsequently be better controlled consciously.

How can the neural effects of biological bottom-up processes such as processing a bicycle or drinking coffee on the one hand and top-down attention processes on the other hand be operationalised for use in teaching fairly theoretical disciplines? Is it possible to make use in teaching of both tacit processes that are automatically elicited but may eventually appear in consciousness, and attention resources that can be focused on particular internal structures for the purposes of improving learning?

The answer is that the neural correlate corroborating an experience, with its many components, highlights how we may organise different kinds of teaching to enhance learning. Here, Barrett's classification of the sources of stimulation into three components – be they fully or only partly conscious – proves conceptually very interesting. It seems that teachers may already teach in ways that accentuate certain aspects (and/or mental 'phenomena') within the neural correlate, by, for example, directing the learner's attention in the direction (reflected as increased activity in the correlate) that the teacher finds the most appropriate.

Experiences that work bottom-up

The complexity of the neural correlate that underlies learning episodes renders informal teaching approaches productive. When teaching is supported by the surroundings (i.e. when Barrett's first component is particularly emphasised), the emphasis is on exogenous attention and perceptual and sensory–motor activities are strongly included in the anchoring of understanding. To some extent, this is the type of learning that is facilitated in outdoor schooling, where objects, events or experiences are woven into the overall understanding[4] but the informal teaching approach assumed in outdoor schooling applies similarly to learning in the laboratory work. When outdoors teacher Lasse Bak Sørensen teaches mathematics and, with special attention to conveying the mathematical conception of volume, encourages students to draw whales in the sand and then gets them to lie down one after another until they fill up the outline, he is addressing student learning bottom-up (Schilhab et al., 2007). Bottom-up teaching occurs because the surroundings are actively involved in learning as so-called material anchors, stimulating the agility of thoughts (Hutchins, 1995).

This is partly because online perceptions become particularly significant (and displace irrelevant thoughts) when student attention is guided by the teacher to external stimuli, and partly because the concrete phenomena at which exogenous attention is directed are actions appealing that ensure that bodily activities – which we may term bottom-up – are involved. In addition, when concrete objects are involved in the process, thinking becomes bodily and multifaceted, so that it can more easily attract joint attention and mutual direct interaction with others. Kirsh writes (2010: 446):

> Things in the world behave differently than things in the mind. For example, external representations are extended in space, not just in time. They can be operated on in different ways; they can be manually duplicated, and rearranged. They can be shared with other people. Tools can be applied to them. These differences between internal and external representations are incredibly significant.

The total sensation of the sea blowing spray, the gull droppings in the sand, the bone-dry seaweed, the light refracted in the sea foam and the salty taste dispersed in the droplets, the cold hands and hair blowing in the wind like a halo are bodily components that impress themselves on our conscious experience. These strong perceptions latch onto learning about the three-dimensionality of the experience of the size of the sand-drawn whale, the feeling of the hard sand on your back as you lie outstretched trying to touch the feet of the person above your head while being tickled on the ankle by the person at your feet.

In the midst of these online perceptions, top-down learning also takes place. As students estimate how many of them it will take to fill out the whale outline, sensory experience is supplemented by endogenous attention to execute the calculation. Here students are tackling the problem top-down, i.e. by controlled attention, because the manoeuvre requires retaining mental images that they themselves must generate, over and above what the environment contributes through exogenous attention (see e.g. Moulton & Kosslyn, 2009).

To sum up: experience-driven teaching uses exogenous attention and the triggering of non-conscious, bottom-up processes. This is what happens with, for instance, outdoors schooling, in which multiple and varied stimulations provide solid learning through massive neural anchoring that registers both conscious and non-conscious processes and thus strengthens memory (see e.g. ‘The Indexical hypothesis‘, Glenberg et al., 2011). The strong sensory stimuli automatically draw and maintain the students’ attention even without the teacher’s direct intervention.

But the teacher can also take advantage of language to reinforce particular sub-processes in the neural correlate. When we are linguistically directed to our surroundings, language helps us to pick out and pay attention to particular stimuli in the available information. When the teacher says, ‘Look at the black adder,’ we all look at the ground searching for a ‘band’ that stands out. The grass, the ground and the black adder all in their presence pose material anchors that affect multiple senses (e.g. Barsalou, 2016). Students may see the snake without instructive help from the teacher; but, with the help of language, the attention process is enhanced, and the coupling between linguistic handling and experience is therefore neurally strengthened.

Language that works top-down

When students learn top-down, they strive to push aside outside influences. This process must be learnt, and here the teacher may seize the opportunity to influence and accentuate particular aspects of Barrett's mental conglomerate. Through language, he or she may amplify the processing of certain experiences in the student in various ways so as to aid the top-down movement of attention (Lapyan, 2012; Schilhab, 2015c). A particularly efficient way to summon the controlled attention of the student is by means of language. In general, verbally encouraging students to concentrate or think of certain things obviously nudges students to entertain and maintain particular perspectives on the world (Tylén, et al., 2010).

For example, children who talk to their parents about emotions and mental states that cannot be sensed in the same way as concrete objects can are far better at understanding what makes people think and behave in certain ways, as demonstrated in non-verbal experiments (Harris et al., 2005). Mental states such as 'sadness' and 'joy,' 'nervousness' or 'jealousy' etc. are special experiences in that they cannot be sensed with identical meaning with others, but only experienced individually in the first-person sense (see e.g. Crane, 1995). The result is that other people's experience of states to which they have no first-person access takes the form of behaviour that is the third-person sense. In contrast, the experience of physical objects admits equal access to everyone to explore and therefore builds some kind of common understanding (consensus). These differences in accessibility make our verbal identification of mental states asymmetrical. When you experience pain, pain is experienced from the inside. But it is nevertheless parents (or the linguistic community as such) who 'decide' when the experience counts as pain. Language is then the vehicle that drags attention to particular sensations, the behavioural pain criteria of others and the interoceptive first-person criteria you yourselves experience (see Schilhab, 2015b). Mental experiences are thus excellent examples of experiences to which we learn to attend (or from which we refrain) linguistically in the mental conglomerate. Although we may all at the individual level experience nervousness, joy, anxiety, etc., it is through others' linguistic instructions that we learn to acknowledge the interoceptive experiences and learn to apply our own previous first-person experiences to behaviours of others (Slaughter et al., 2007)[5].

However, the teacher's language use may also operate by more indirect methods. By using linguistic expressions that are particularly emotionally significant for the student, the teacher can better control what the student is attending to and concentrating on. This becomes evident in the case of learning about phenomena that we cannot experience through perception (Schilhab, 2011b; 2011c). This kind of learning is relatively widespread in formal schooling and especially in the theory-heavy STEM disciplines (science, technology, engineering and mathematics) because much knowledge cannot be directly sensed. For instance, we have never experienced the famous kings who embody the list of kings. And we will never get to pat a *Tyrannosaurus rex.* This means that we cannot get quite the same sense of abstract knowledge through sensing the impact on our own body (as hypothesised by the first component in the quote by Barrett) as with plants that we experience in our ecosystem or the outlined whales on the beach as described above. In these cases, we have to try to make sense of the thing by associating the kind of knowledge with something else that makes sense to us.

'Derived embodiment'

If you cannot directly experience the referent of a concept, you are dependent on the explanations provided by the teacher, who conveys when the concept applies (this was also relevant in learning about the mental lives of others, as discussed above). Here the teacher must try to find metaphors or linguistic images to which learners can relate (Åberg, 2013). These images will typically prove most useful if they involve something that the student has actually experienced first-hand. Due to the complex neural conglomerate discussed in the beginning, the self-experienced appears easier to activate. For instance, like with the concept of 'dog', we understand the concept 'banana' through remembering the sensory qualities of banana (González et al., 2006; Pecher et al., 2011), and the bodily sensation associated with the experience can be used to make the abstract knowledge understandable. So the teacher's task could be to highlight experiences already experienced by the student and therefore significant. This re-enaction generates an experience as if the referent was a tangible object perceived.

The same problem applies to abstract knowledge with no obvious physical properties, such as the notion of a limit in mathematics or such concepts as 'democracy' or 'empathy'. Here there is no readily available, in the sense of tangible, existence other than what may be coupled to speech activities – that is, activation of facial muscles, vibration of the vocal cords or the emotions associated with the concept (Vigliocco, et al., 2013).

When this kind of knowledge is to be established, it is difficult to point to comprehensible instantiations in the surroundings and understanding is therefore entirely dependent on linguistic explanation. Here, language and that to which language refers constitute the 'tangible anchor' on which the student relies to capture what the abstract concept covers.

How can language constitute a tangible anchor? If we turn back to the starting-point of Barrett's three components, it is the neural correlate of linguistic expressions composed of several parts that includes perceptual and emotional components (that was why 'banana' could be re-enacted through sensory experiences). The teacher can use certain linguistic concepts to endorse specific emotions and 'experiences' in the student, and thus activate a particular neural conglomerate to which the intangible concept may now become associated.

When students learn about the concept of 'interoception,' for instance, they may successfully acquire the concept if they imagine the interior as a kind of landscape with different viewpoints and alternating ridges, because of direct physical experiences with an actual geographical landscape. When the teacher uses the experience of an actual landscape as a symbol of 'interoception,' the newly formed neural correlate of the concept may also include the 'transferred' experiential contributions that give the abstract notion a form of 'transferred physicality' also known as 'derived embodiment,' (Schilhab, 2011b; 2012, 2015b).

In derived embodiment, it is the conversation – and thus it is top-down activation – that is crucial for learning. Here, language helps us to identify what in our imagination we must focus on. It is the experiential conscious element to be apprehended as if it were experienced in reality, and it is this process that the teacher may factually endorse.

To sum up; language helps to make certain experiences stand out drawing on the imagination (the third component in Barrett's quote). Here, language identifies which experiences to associate when we learn about phenomena or events that we cannot experience directly. We could try to understand *Tyrannosaurus rex* by imagining a giant lizard as tall as the second floor with a tiger's taste for meat. Using language, we re-enact emotions and sensations, such as lizards or chameleons from the zoo; we imagine the distance from the ground level up to the second floor to represent the idea of *T. rex,* which would otherwise lack corporeal sensations because no concrete experience is involved. Once *T. rex* is also characterised as dangerous, the experience of 'dangerous' is re-enacted (Schilhab, 2015c).

As we learn through language and imagination, the conversation functions to encourage the learner to focus on specific parts of the images created in an attempt to grasp meaning through re-enacting past experiences. The mechanism that sustains understanding of events or phenomena without direct experiences strongly resembles the mental and neural occurrences that accompany direct experiences. These are the elements of the correlate associated with the senses. But since the exogenous attention is almost idle because of the lack of accessible input, controlled attention is left for the teacher to manipulate. The appropriate handling is not easy, though. It requires that the teacher at one and the same time grasps what the learner actually mentally construes and simultaneously keeps track of the imaginings the learner ought to form to optimise understanding. Sometimes the learner may not imagine appropriately to catch well-functioning ideas, or may have successfully caught only fragments of the mental image required for optimal learning results. In other cases, the learner may not recognise the necessity of multiple simultaneous images. The teacher's task is then to get the learner to focus on the right parts in the right way. And this process is usually pursued through continuous conversation. The conversation is crucial when what has to be learnt cannot affect the senses as concrete objects do.

Discussion

Although it might be the turn in the acknowledgment of tacit (implicit) processes in cognitive neuropsychology that forces the push of a new biological agenda in pedagogy (Glenberg, 2015), translation of neuroscience research into the area of teaching is bound to encounter criticism, This criticism addresses both the specific level that concerns how embodied cognition might be applied to augment learning and teaching (e.g. STEM disciplines) in general and the broader level that concerns the unusual mixture of philosophical positions.

So, what is it about the seemingly reductionist neurocognitive approach that warrants its use in teaching?

Firstly, in many cases, the notion of the 'neural correlate' is an abstraction inferred from the ongoing physical activity in question that leaves the actual interpretation and derived anticipatory predictions rather weak. In such cases, the neural correlate is to be understood as a construct not empirically established, yet meaningfully ascribable. Moreover, the stimuli that occur outside (externally) or inside (internally) are, though labelled in singular terms, most certainly composite in nature. It seems meaningless to assume that cognition can be described as the 'result' of a single input, though cognition definitely implies action and reaction relations and therefore lend itself to images of selective input-output associations. Since learning of abstract concepts as defined here relates to phenomena with no physical reality in the normal sense of the term, investigation of such learning naturally invites the level of neural representations, even if the perspective balances on the brink of accusations of reductionist inclinations. Simply because the neural representational approach is excellent for articulations of phenomena that are either present or absent (e.g. abstract) (e.g. Wilson, 2002; Schilhab, 2015b). Moreover, and of significant importance stressing the neural correlate allows for the inclusion of implicit processes, non-conscious actions, and automatic responses, abundant in human behaviours.

Secondly, many teachers and professional educators intuitively use visual instruction and metaphors when they need to communicate a message and get students to understand difficult issues. An understanding of the complexity of learning as demonstrated at the neural level gives a detailed sense of the diverse learning qualities that different teaching approaches may offer.

Concerning the unusual mixture of philosophical positions, within educational neuroscience, there is a clash between naturalised perspectives in the sense that these are taken for indisputable truths about the world and our place in it, and the social educational perspectives in which the prevalent epistemic stance is said to be that of constructivism. However, I assert that these disagreements and controversies would be expected in any newly emerging science. Discussing the heterogeneity from a more Kuhnian perspective would dissolve many of the seemingly problematical disagreements between the various camps championing different views on the viability of educational neuroscience. Reconceptualising these disagreements and controversies in light of the concept of pre-paradigmatic phases would help distil and ultimately analyse the idiosyncrasies of ongoing educational neuroscience debates on the relationship between neuroscience and education, thus qualifying the importance of a new philosophical approach that embraces both of the mother positions. Although future educational neuroscience is bound to be fundamentally transdisciplinary in the same way as testified by the initial phases future researchers born into tackling the tensions between aspects in educational neuroscience will probably nurture yet unseen varieties of hybridisations between mother disciplines (Howard-Jones, 2010)[6] Alternatively, if this proves too difficult, they will redefine educational neuroscience into something scientifically viable (e.g. Colvin, 2016).

Conclusion

In this paper, I have claimed that knowledge of the composition of the neural correlate that sustains learning experiences can be operationalised in such a way as to inspire teachers to optimise learning conditions. In particular, I assert that an understanding of this process gives the teacher conceptual tools for understanding how specific measures – instructional and experiential teaching, as well as linguistic explanations – may work. This kind of teaching has always been conducted, and therefore it is pertinent to ask whether knowledge of the neural correlate really radically changes anything in practice. Although the present review is tentative, as the theory of derived embodiment is relatively new (Schilhab, 2011a; 2011b; 2012; 2013b; 2015c) and has yet to be fully established, significant insights are to be gained from the biological approach to cognition.

The neurobiological perspective highlights how learning as a multifaceted process points to a corresponding number of possible actions. It also shows how attention and consciousness are decisive with respect to what is learnt, as well as how these attention processes can be activated through language.

From the neural perspective, then, the teacher acquires a conceptual understanding and operationalisation that are quite unique. Finally, although learning is individually constrained to the extent that the neural correlate emerges in the learner, the teacher has a decisive influence on how and on which component parts the learning correlate is amplified or toned down. From consideration of the neural correlate, it becomes obvious that all learning draws upon both bottom-up and top-down processes. Learning is most fruitfully obtained, therefore, when the individual and the social meet.

Notes

[1] Kaplan & Berman (2010, s. 48), cite Hebb: ‘in the simplest of terms, attention refers to a selectivity of response. Man or animal is continuously responding to some events in the environment and not to others that could be responded to (or noticed) just as well.’

[2] The second component in Barrett’s quote is also of relevance in this context. Interoception seems to depend on some degree of monitoring, e.g. when in pain or just plain detection of well being (see Chun et al., 2011). It is likely that non-conscious interoception may occur (on a related hypothesis see for instance Goldman & Shanton, 2010).

[3] Please note that we may also consciously modulate exogenous attention in order to voluntarily neglect certain external stimuli. In that case attention also works top-down

[4] Sometimes the rationale behind outdoor schools is to enhance physical and social well-being (Bentsen et al., 2013).

[5] In contemporary social neuroscience, theory of mind theories conjecture a close association between the function of mirror neurons and mirror-neuron systems and the understanding of other

minds (ToM). Increasingly, the relation between ToM and mirror neurons seems to depend on intensive learning sessions (see Heyes, 2010a; 2010b)

[6] Such researchers might for example graduate from actual educations such as 'Mind, Brain and Education', initiated by the Harvard Graduate School of Education's societies.

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*Dr Theresa Schilhab - Future technologies, culture and learning, Danish School of Education, University of Aarhus, Copenhagen, Denmark, tsc@edu.au.dk